A Combined Laser-communication And Imager for Microspacecraft (ACLAIM)

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ABSTRACT

ACLAIM is a multi-function instrument consisting of a laser communication terminal and an imaging camera that share a common telescope. A single APS- (Active Pixel Sensor) based focal-plane-array is used to perform both the acquisition and tracking (for laser communication) and science imaging functions. ACLAIM was designed based on all commercially available catalog items. The instrument opto-mechanical design and performance is described here.

Key-words: Laser Communication, Optical Communication, Science Imaging, Micro-spacecraft

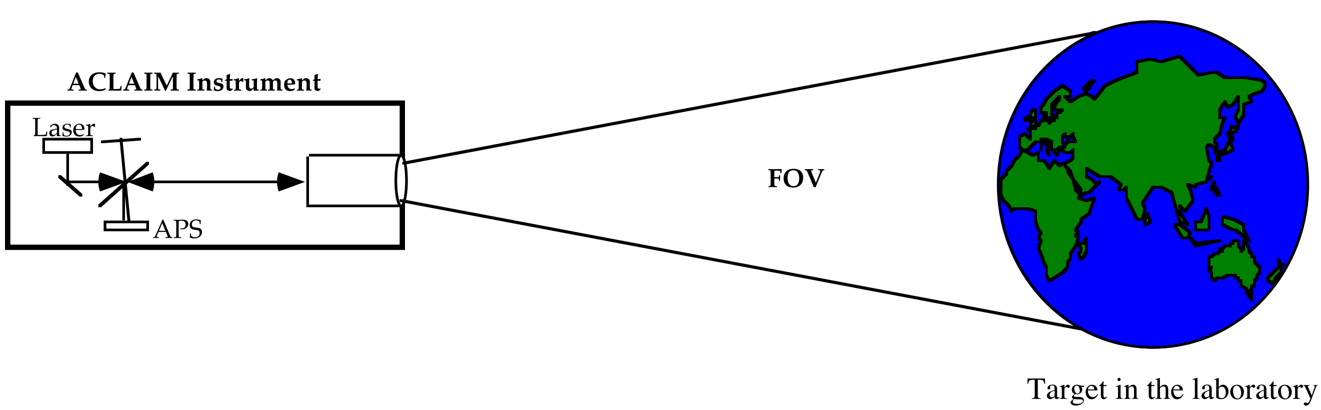
1. INTRODUCTION

The Jet Propulsion Laboratory (JPL) is developing very small spacecraft (called microspacecraft) technology for future NASA missions. The mission focus is on planetary and deep-space missions. A spacecraft breadboard has been assembled. This breadboard will serve as a testbed for new technologies that are aimed at miniaturizing the various subsystems within a spacecraft. The micro-spacecraft breadboard includes the typical subsystems: a power subsystem; communications to talk to the control station; a command and data subsystem; gyros and a propulsion subsystem for attitude control, structure and a camera. A new mass- and volume-saving technology concept is referred to as the multi-function telescope (MFT). MFT is intended to be a single aperture optical instrument combining the functions of laser telecommunication, visual imager, and in the future, IR spectrometer and navigation. The ACLAIM instrument described here, was built to demonstrate two of these functions, laser communication and science imaging, within a single instrument.

Figures (1) and (2) schematically show the data acquisition and transmission scenarios. In laboratory tests, the ACLAIM

Figure 1. ACLAIM Data Acquisition Scenario

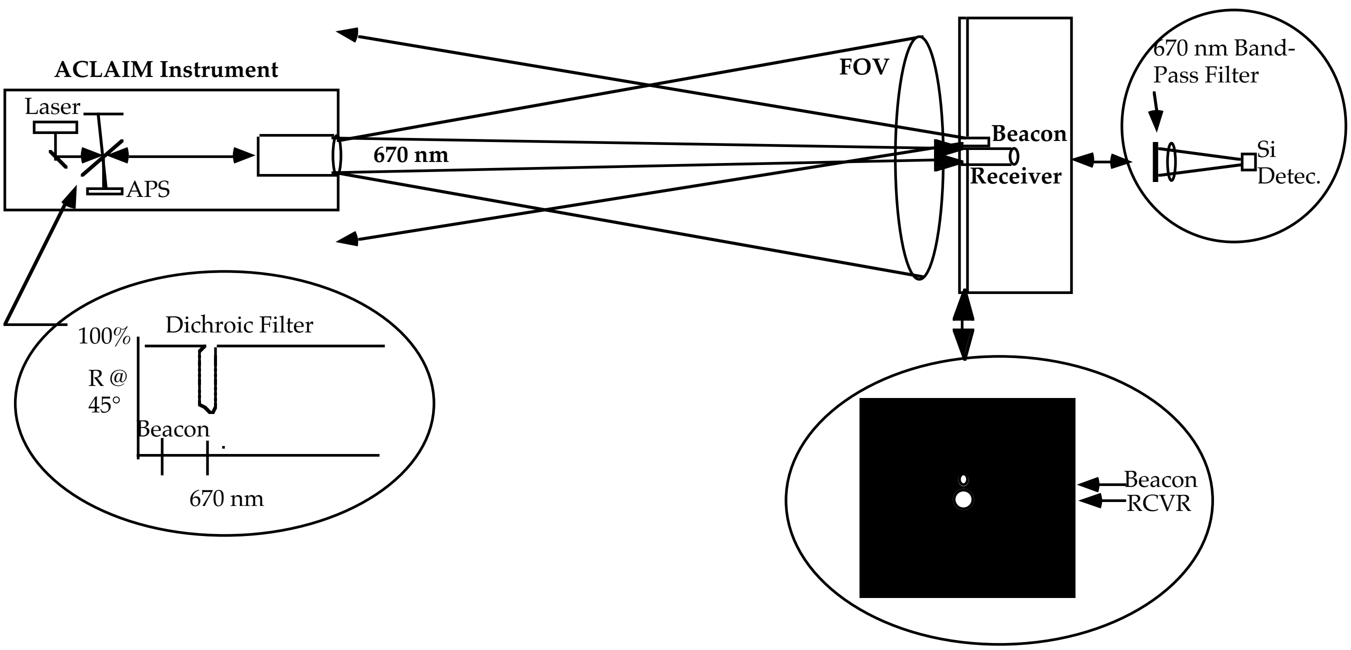
- The μS/C is turned to bring the RCVR within the FOV of the target
- A picture of the target is taken and stored in the S/C memory



instrument is used to take a picture of an object within its field of view (FOV). The picture is then stored in the spacecraft breadboard's memory and is subsequently modulated on the laser transmitter beam. A receiver with an aperture diameter of 25 mm detects the transmitted beam and demodulates the signal for display on a monitor. The ACLAIM instrument includes a two-axis fine-pointing mirror for off-set pointing of the beam onto the receiver when the spacecraft is intentionally miss-pointed. To do this, ACLAIM uses a beacon source co-located with the receiver. This instrument was designed, assembled, tested and delivered for incorporation with the micro-spacecraft breadboard.

Figure 2. ACLAIM Data Transmission /Reception Scenario

- The microspacecraft breadboard is turned to the receiver within the FOV of the instrument's camera
- The transmit beam is intentionally miss-pointed away from the receiver
- The instrument locks onto the beacon and fine-points the beam at the receiver
- The stored data is transmitted to the receiver, detected data is demodulated for display



The pre-set requirements for the ACLAIM instrument were:

<u>Imaging</u>	
Range	≥ 7 m (across the laboratory)
Field of view of the instrument	≥ 10 mrad
Size of images	~ 15 cm x 15 cm
Resolution	> 5 pixels
<u>Transmit Data:</u>	
- Optical power	≥ 1 mW
- Format	On-off keying (OOK)
- Rate	≥ 10 Mbps
- Wavelength	

- Clear aperture	670±30 nm (visible diode laser) ≥ 4 cm
Spatial Acquisition:	
- Acquisition uncertainty range	Acquisition over attitude uncertainty of ± 5 mrad
- Beacon irradiance	Eye-safe
- Pointing accuracy	Not applicable (wide angle LED)
- Beam-steering range	≥ ± 6 cm at the receiver
- Beam steering control bandwidth	> 10 Hz
- Point-ahead	None
Interfaces to Terminal	
- DC Voltages	±5 and ±12 V
- Transmit data format	TTL digital
- Command/status	On/off command to terminal from host s/c.
Physical Characteristics	
- Overall volume	< 10 x 10 x 20 cm^3
Operating Environment Temperature:	Laboratory
Redundancy:	None

2. OPTICAL DESIGN

The optical system for the instrument was designed using the CODE V™ program. To avoid excessive cost and delivery time, the optical design utilized only those components that were commercially available off-the-shelf. An exception was the dichroic beam-splitter which has high reflectance in the 500-900 nm region except for a narrow-band (± 20 nm) where it has high (> 70%) transmittance at the laser wavelength (670 nm). A schematic of the instrument's optical paths is shown in Figure (3). The optical path of the instrument contains three channels: the receive channel; the transmit channel; and the bore-sight channel. The receive and transmit channels partially share a common path. The receive channel extends from the entrance of the instrument (where beacon light enters and the transmitted light leaves) to the dichroic beam-splitter and continues to the APS imager. The beacon light (a green color LED for laboratory tests) falls on the APS array also and will be used for acquisition and tracking functions. In planetary communication, the sun-illuminated earth extended-source, or a laser beam point-source may constitute the beacon. Two sets of eye-pieces were used to shape the receive beam (object image or beacon) prior to incidence on the focal plane array.

The transmit channel starts from the end of the fiber pigtail. A collimating lens is positioned in front of the fiber to form a circular collimated beam. The optical elements in this channel are the steering mirror, used for fine-pointing and servoing out spacecraft vibrations, the beam-splitter, and an eye-piece. The laser beam is directed by the fine steering mirror to the dichroic beam-splitter. The boresight channel retro-reflects the laser light reflected from the beam-splitter onto the imager where it is used as a pointing reference. This particular acquisition and tracking architecture was described earlier by Lesh and Chen [1]. Table [I] below describes the optical elements that were used in the ACLAIM instrument. The mechanical design was performed with the CV™ computer-assisted drawing program directly from the Code V™ optical files.

Table I. Description of ACLAIM Optics

Component	**Performance**
Telescope aperture diameter	53.571 mm
Telescope effective focal length	300 mm
Exit pupil location	Front edge of lens housing
Eyepiece focal length	21.6129 mm
Telescope magnification	20.48 at 10 m and 10.16 at 10 m
Telescope/eyepiece magnification	13.881
APS detector and pixel size	5.2224 mm, 256x256 array at 0.0204 μm
Telescope field-of-view	± 0.9487 deg
Eyepiece field-of-view	± 6.8889 deg
Fine-pointing mirror	± 1.146 deg x ±2.86 deg

Figure 3. ACLAIM Optics Concept

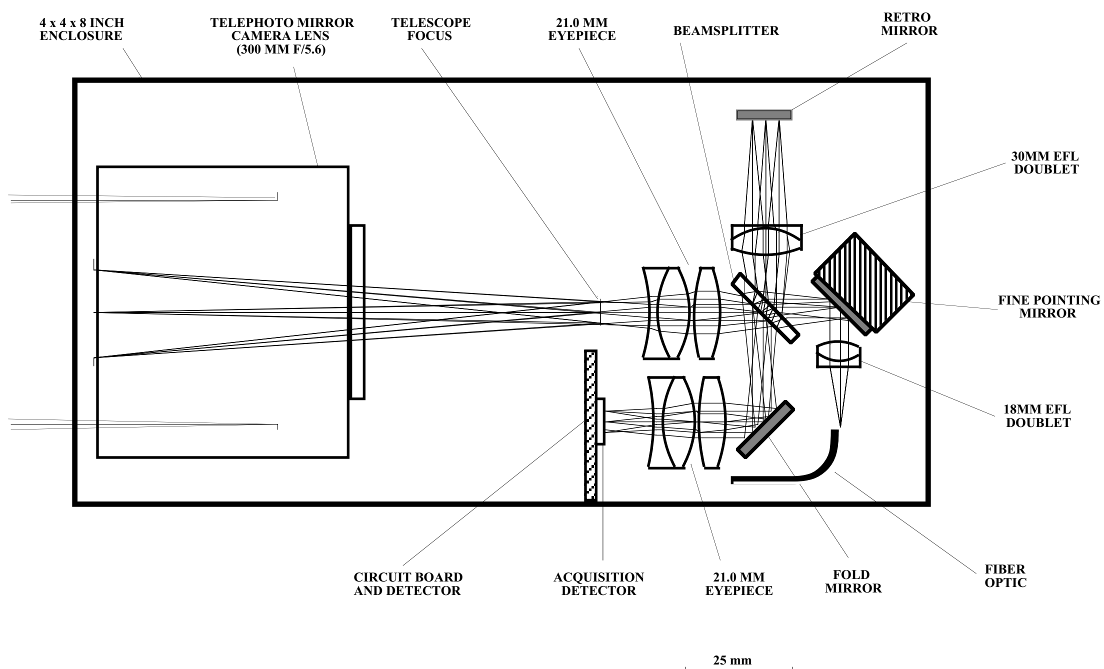


Table (II) provides a list of the components that constitute the ACLAIM instrument and their properties.

Table II. ACLAIM instrument components and specifications

Telescope:	
Type	Telephoto mirror lens (Kalimar)
Effective focal length	30 cm, F5.6
Dimensions	5.357 cm (largest optic diameter), 6.35 cm long
Field-of-view	± 0.978°
Laser Transmitter:	
Type	Diode Laser, fiber-pigtailed (Power Tech. Inc., #PMT-04)
Beam diameter	4 micron
Fiber numerical aperture	0.11 (single-mode fiber)
Dimensions	2.55 cm diameter x 6.5 cm long
DC power requirements	± 5 V
Data input	TTL digital signal < 20 MHz in frequency
Fine-Pointing Mirror:	
Type	Two-axis voice-coil actuator (BEI model # LA08-05)
Mirror diameter	1.8 cm
Mirror surface quality	l/10
Rotational angle (each axis)	± 1.146° in one axis and ± 2.86° in the second axis
Overall dimensions	2 cm diameter, 1.5 cm long
Driving current requirements	0.6 A at peak force
Acquisition/Tracking Detector:	
Type	APS (active pixel sensor, fabricated at JPL)
Pixel size	13.8 mm x 14.4 mm
Active area	5.2 mm x 5.2 mm (256 x 256 pixels, 20.4 mm pixel-to-pixel)
Pixel fill factor	0.3

3. THE INSTRUMENT AND EXPERIMENTAL RESULTS

The optical elements were fitted into their respective cells and bonded using low outgassing bonding material. The cells were then attached to a small optics bench and were optically aligned with the telescope such that a uniform image could be observed on the APS array. Also, the laser spot size from the boresight channel formed a well-defined image at the APS detector. The modulatable diode laser transmitter and the APS imager are located under the optics bench to make the assembly fairly compact.

Figure [4] shows a picture of the instrument following assembly. This instrument was used to take high quality images and to transmit the images to the receiver. During these tests the transmitter was manually aimed at the receiver. The software to accomplish pointing based on data from the beacon on the APS focal plane array has not been completed yet. Once the software is implemented with the ACLAIM instrument and the beacon source is within the field-of-view of the APS array, the laser beam will be pointed by the instrument at the direction of the beacon (co-located with the receiver).

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[1]. C. C. Chen and J. R. Lesh, “Overview of the Optical Communications Demonstrator,” Proceedings of SPIE, Vol. 2123, pp.85-89, Los Angeles, CA, January 1994.